Coverage Holes Detecting and Healing in Hybrid Wireless Networks

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ABSTRACT

Nowadays, wireless sensor network which consists of numerous tiny sensors has been widely used. One of the major challenges in such networks is how to cover the sensing area effectively and maintain longer network lifetime with limited energy simultaneously. In this paper, we study hybrid network which contains both static and mobile sensors. We divide monitoring area into Delaunay Triangulation (DT) by using of Delaunay theory, based on the DT we estimate static sensors coverage holes and then work out the position of assisted mobile nodes in each triangle. In addition, we simulate our algorithm and compared with the previous methods on the platform MATLAB. The results show our algorithm is simpler and more efficient than the previous.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability;

KEYWORDS

Coverage, Estimate, Healing, Hybrid sensor networks

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1 INTRODUCTION

With the development of the network technology and extending of applied range of wireless sensor networks(WSNs), wireless sensor networks have gained widely attention for applying in natural disasters and some dangerous environment [6]. For example earthquake stricken area and old-growth forest fire. Dangerous environment exits huge security risk for the rescuers if they need enter the primary scene, but by casting a mount of sensors to the under surveillant area can not only solve the security risk problem but also make up WSNs networks to obtain the instant information of disaster area. However, because of the sensors are randomly deployed and may lead to the coverage holes, and as the data-centered network how to achieve efficient coverage is a very worthy issue to research [4].

Ghosh et al. [2] proposed the COVEN algorithm to increase the coverage, they based on the Voronoi diagram to make accurate calculation about the coverage holes. The method divided the detecting field into many cells and then divided every cell into several triangles, next discussed the relationship between sensor radius and Voronoi edge l_{ij}, then worked out the uncovered area in every cell, finally dispatched the assisted sensors to heal the coverage holes. The positions of assisted nodes in COVEN algorithm must satisfy three conditions as follows:

- P_i, the positions of assisted nodes must be located on the line that bisects the inner angle formed by V_i, which is Voronoi vertex;
- P_i is located in the Voronoi polygon that is constructed by current sensor nodes;
- The distance between sensor node S_i and assisted node P_i is the minimum value compared with double sensing radius, $d(S_i, P_i) = \min\{2R_s, d(S_i, V_i)\}$.

Obviously, it could increase the coverage to some extent, but it did not give the concrete algorithm about how to work out the number of assisted sensors, in addition to this, the calculation of coverage hole is relatively complicated.

Our paper resemble the paper [7] in frame. The general idea is to detect the coverage holes in every triangle, then dispatch nodes to heal the holes. What is different from previous work mainly is the simpler divide approach. In this paper, we study the area coverage of hybrid networks [7]. Assuming the initial network deployed a certain number of static nodes in the sensing field stochastically. At first, we use static sensors to estimate the coverage holes in the random distribution sensor network, and then calculate the optimal position to deploy the assisted sensors which can heal the coverage holes. Compared with the existing methods, our approach mainly shows several advantages as follows.

- Our calculation method of coverage is simpler than other works, the simulation in section 4 shows that our approach outperform previous works by get a higher coverage ration.
- We give out the optimal position to heal the the coverage hole.

The rest of the paper is organized as follows. In Section 2, the system model and problem statement is illustrated. Then, we propose the theoretical framework of the problem and our coverage algorithm in Section3. In section 4, performance evaluation and analysis are presented. Conclusions and future work are given in the last part Section 5.

2 SYSTEM MODEL

The WSNs are consisted by many mobile sensors and static sensors, the fundamental problem in this paper is how to enhance the coverage by finding and healing coverage holes. Next, we will introduce some preparative knowledge which are used in the following analysis.

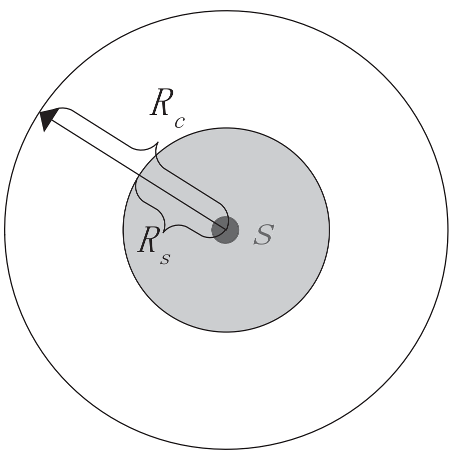

Figure 1: Communication and sensing models

2.1 Communication and Sensing Model

Each sensor has communication capacity and sensing capacity, R_c is defined as communication radius and R_s is defined as sensing radius, Figure 1 shows the communication and sensing models. If and only if the distance between two sensors is within R_c, they can communicate with each other, otherwise the node is isolated. Tian et al. [5] proved that $R_c \geq 2R_s$ is the sufficient condition of tight lower bound to ensure network connectivity.

Delaunay triangulation is an important data structure in computational geometry [1]. The most significant property we use in this paper is that:

(1) Maximum empty circle characteristic. The property decides the Delaunay triangulation is unique and any four points must not construct a circle.
(2) Maximize the minimum angle. The characteristic means the composition of triangle is reasonable and not too narrow.

We can detect the coverage holes in each Delaunay triangle by discussing the R_s and the circumcenter C_0 of the triangle. If C_0 is not covered by the sensor node of triangle, there will exist coverage holes in the triangle. Given N static sensors S_1, S_2, $S_3 \cdots$, we can get the Delaunay Triangulation (DT). For example, we choose 50 random nodes to construct Delaunay Triangulation in a 100×100 scene by MATLAB as shown in Figure 2.

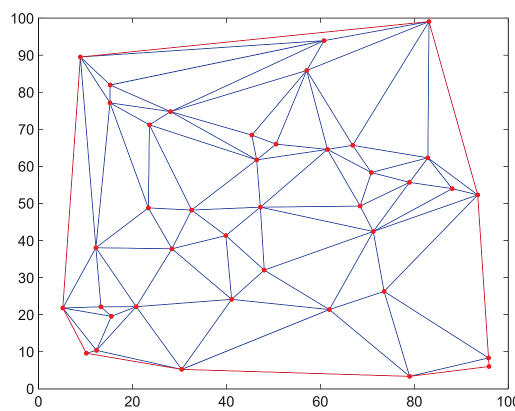

Figure 2: Delaunay Triangulation (DT)

2.2 Problem Statement

The coverage of the wireless sensor network can be divided into area coverage, point coverage and barrier coverage. In this paper we mainly discuss the scheme of position selected. At first, we assume a $100m \times 100m$ scene and deploy a certain number of static sensors randomly in this area. The problem we are prepared to address is how to choose the position to deploy healing sensor nodes. To solve this issue, we need to divide the scene into small cell by Delaunay Triangulation and then discuss the position of assisted node in each cell.

To simplify the analysis of the problem later, we assume that all sensors' sensing range is a circular with the radius of R_s, and R_c is defined as communication range. In order to facilitate reading, we introduce some significant parameters as Table 1:

Table 1: main notations.

Notation	Definition
S_i, M_j	Static sensor and mobile sensor
θ_i	Angle of three Delaunay triangle
R_s, R_c	Sensing radius and communication radius
P_i	Position of mobile assisted sensor
C_0	The circumcenter of the $\Delta S_1S_2S_3$
$S_{uncovered}$	Uncovered area of the triangle
$d(s_i, s_j)$	Euclidean distance between s_i and s_j
μ	Input parameter to round the number of assisted sensors

3 COVERAGE HOLES DETECTING AND HEALING

In this section, we will elaborate the problem we have proposed above and the Heal Coverage Holes Algorithm(HCHA). The network we research is hybrid, which consists of both static and mobile sensors. During the network initialization, static sensors construct the DT.

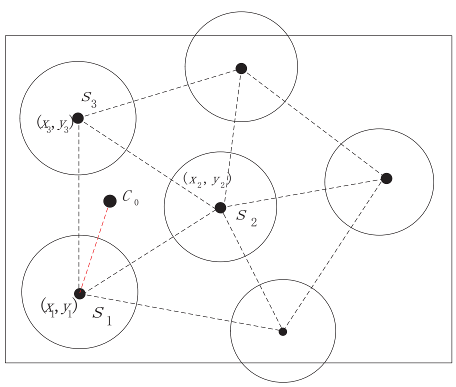

Figure 3: Nodes construct triangle.

Step1. Detect if there exist the coverage holes. The approach is based on the DT which can constructed by the static sensors at the beginning.

We assume a $100m \times 100m$ scene, in the scene senors are deployed randomly may cause the coverage holes. Helping with the DT, we can judge if there exist coverage holes or not. Nodes construct triangles as Figure 3 shows, C_0 is the circumcenter of the $\Delta S_1S_2S_3$ and the distance $d(S_i, C_0)$ is circumradius R. If $R_s > R$ then there does not exist coverage hole between the three sensors, if the $\Delta S_1S_2S_3$ is an acute triangle and $R_s < R$ then there must exist coverage holes between three sensors [3] .

We know C_0 is the circumcenter of $S_i(1, 2, 3)$, according to geometry we can get conclusion easily that the distance between C_0 and S_i is equal , so if C_0 is covered by sensor S_1, then C_0 must be covered by $S_1's$ neighbour nodes S_2 and S_3 as the Figure 4(b) demonstrates. It is apparently that the

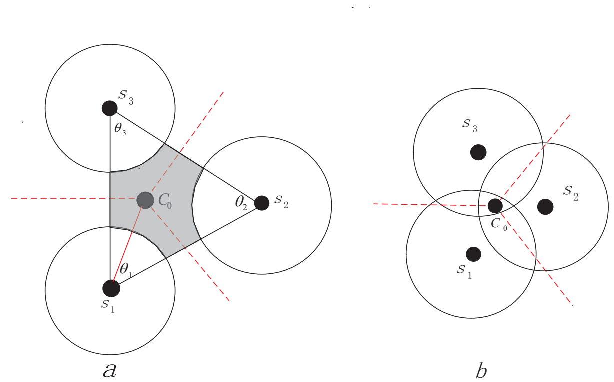

Figure 4: Coverage holes estimated.

triangle area constructed by S_1 and its two neighbours do not exist coverage holes.

Step2. Heal the coverage holes by finding the position of assisted nodes.

In order to heal the coverage holes efficiently, it is easy to satisfy the bow area as Figure 5 shows is minimum. We introduce two assisted angles α, β and P_0 which is the inner of $S_{\Delta p_1 R_1^1 R_2^1}$ to simpler the calculation. By mathematical theory we can get the area of $S_{\Delta p_1 R_1^2 R_2^2}$ and $S_{sector2}$, and $S_{sector1}$:

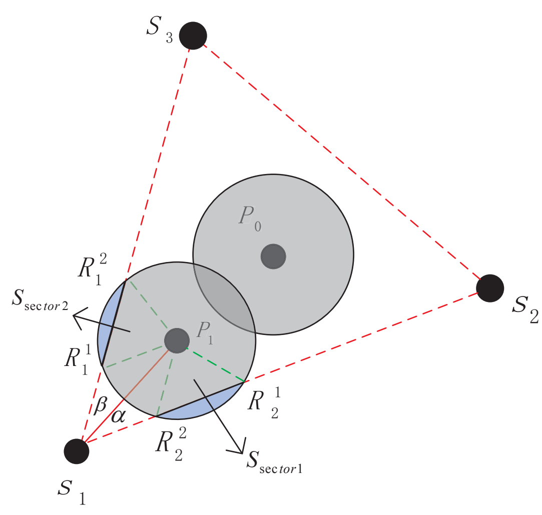

Figure 5: Node P_1 lies in the angle bisector.

$$\begin{cases} S_{\Delta p_1 R_2^1 R_2^2} = dsin(\alpha)\sqrt{R_s^2 - d^2 sin^2(\alpha)} \\ S_{\Delta p_1 R_2^1 R_2^2} = dsin(\beta)\sqrt{R_s^2 - d^2 sin^2(\beta)} \\ S_{sector1} = \frac{R_s^2}{2}(\pi - 2\arcsin(\frac{dsin\alpha}{R_s})) \\ S_{sector2} = \frac{R_s^2}{2}(\pi - 2\arcsin(\frac{dsin\beta}{R_s})) \end{cases} \tag{1}$$

ALGORITHM 1: Deploy assisted node in each triangle

Initialization: Randomly deployed sensors, construct DT.
Input: Sensors' locations $(x_1, y_1), (x_2, y_2)...$
Output: Coordinates of the assisted mobile node.
if $R_s > R$ **then**
  There does not exist coverage hole between the three sensors
else if $\Delta S_1 S_2 S_3$ *is an acute triangle* **and** $R_s < R$ **then**
  There must exist coverage hole between the three sensors
  Set inner center P_0 of $\Delta S_{s_1 s_2 s_3}$
  Set the angle bisector $(\overline{P_0 S_1}, \overline{P_0 S_2}, \overline{P_0 S_3})$
  Assisted senors should be set on $(\overline{P_0 S_1}, \overline{P_0 S_2}, \overline{P_0 S_3})$
endif

we can get the $S_{\widehat{R_2^1 R_2^2}} = S_{sector1} - S_{\Delta p_1 R_2^1 R_2^2}$, in a similar way $S_{\widehat{R_1^1 R_1^2}}$ can be calculated. Finally, the blue area is:

$$\begin{aligned} S_{Bowarea} &= S_{\widehat{R_1^1 R_1^2}} + S_{\widehat{R_2^1 R_2^2}} \\ &= \sum_{\phi=\alpha,\beta} \frac{R_s^2}{2}(\pi - 2\arcsin(\frac{d sin\phi}{R_s})) \\ &- d sin(\phi)\sqrt{R_s^2 - d^2 sin^2(\phi)}. \end{aligned} \tag{2}$$

According to the extremum theorem of the two function , easily we can get when $\alpha = \beta$, $S_{Bowarea}$ is the least, thus $\angle S_2 S_1 P_1 = \angle S_3 S_1 P_1$, so $\overline{P_1 S_1}$ is the angular bisector of $\angle S_2 S_1 S_3$, then we prove that assisted sensor must lie on the angle bisector of $S_{\Delta s_i s_j s_k}$ which is constituted by three neighbor nodes.

Pseudo-code is given in **ALGORITHM 1**.

4 PERFORMANCE EVALUATION AND ANALYSIS

In this section, we will conduct comparative simulations about our algorithm HCHA and COVEN, the main simulation platform we used is Matlab. In order to make a remarkable contrast, we compare HCHA deployment with the random deployment and COVEN deployment in paper [2]. The simulation area we choose is $100m \times 100m$ and sensing radius R_s is $5m$, μ is 0.5, red nodes represent mobile sensors and blue represent static sensors.

As shown in Figure 6 the coverage ratio of HCHA deployment is higher than both random deployment and COVEN deployment. The HCAH deployment has a better performance when the number of total nodes is less than 120, and when the the number of total nodes is between 120 and 240, the HCHA still has a higher coverage ratio than both of COVEN and random deployment, as to the number of total nodes higher than 240, the coverage ratio between HCHA and COVEN hold the line.

The Figure 7 has displayed the optimal position of assisted sensor. Three blue nodes represent the static sensors and they construct the DT which is displayed by the blue triangle. To illustrate the optimal position of assisted sensors which are used to heal the coverage holes, we construct the DT with coverage holes at the beginning. The red points represent the optimal position of assisted sensors, the red circles show

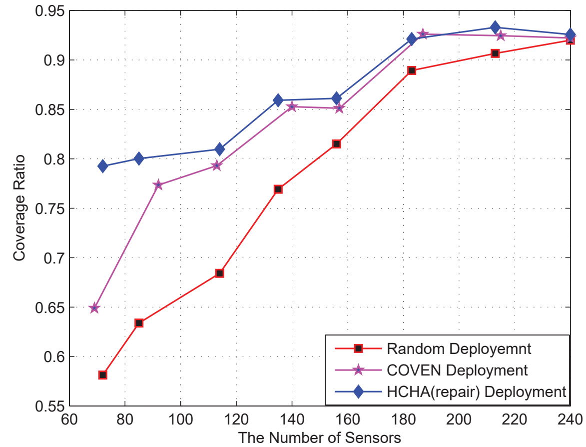

Figure 6: Coverage ratio.

the healed coverage holes. The optimal position of assisted sensors should be the angle bisector of three neighbor nodes as we have proved.

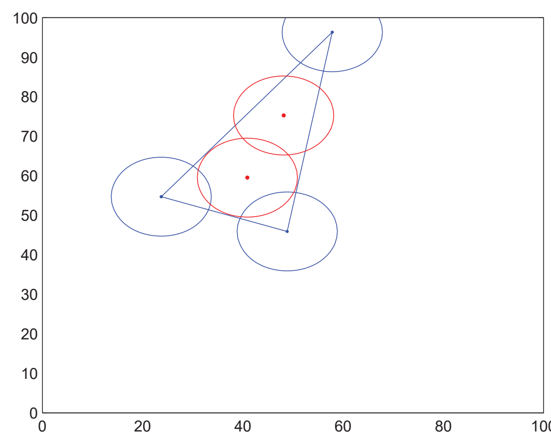

Figure 7: Optimal location of assisted sensor in HCHA.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we study the coverage problem in hybrid WSNs and we give HCHA algorithm based on Delaunay to estimate as well as heal coverage holes in the monitoring area, besides we solve the boundary coverage holes estimation and consider multiple assisted nodes healing deployment strategy.

For the future work, we are prepared to research the quantitative range of assisted nodes which is related to parameter

k , where k is the ration between R_c and R_s. In addition, we are going to research the detail healing method by collecting the neighbour sensor nodes information.

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